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November 4, 1993

Office of the Secretary
Federal Communications Commission
Washington, DC 20554

ADDENDUM

RECEIVED

FCC - MAIL ROOM

Subject: Notice of Proposed Rule Making
ET Docket # 93-62
Guidelines for Evaluating the Environmental
Effects of Radiofrequency Radiation

Subsequent to the formerly submitted NPRM comments dated 7/27/93 by our organization, we wish to submit the enclosed report and data from the U.S. Naval Aerospace Medical Research Laboratory (NAMRL) containing critical information on the efficacy of RF Radiation Protective Clothing made from the material called Naptex.

The *Letter Report to Sponsor*, submitted by NAMRL to both the FCC and OSHA in response to the contract between NAMRL and Maxwell Safety Products, details the efforts made to evaluate the performance of Naptex RF Protective Clothing in the frequency range of 2 MHz through 400 MHz. It is in this range that Induced Current is such a considerable issue, which, in fact, is effectively mitigated by using the protective apparel as discussed.

Based on this report and subsequent testimony of the author, Dr. Richard Olsen, we believe that the Induced Current issue is now provided a viable, effective and economic way to be transcended.

Also enclosed for evaluation are further tests by the NAMRL team up into the microwave region, showing exceptional performance of the Naptex RF suit without overshoes down to 400 MHz.

With the latest information showing thresholds beyond virtually any practicable application, Naptex is now recommended for use in the entire frequency spectrum of broadcast and microwave, including AM radio.

For more information, inquiries are most welcome.

Very Truly Yours,

Joseph A. Amato
JAA:lml

Enc.

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LETTER REPORT TO SPONSOR:

MEASUREMENTS OF ANKLE SAR AND BODY-TO-GROUND CURRENT IN A SUIT-PROTECTED HUMAN MODEL FOR NEAR-FIELD EXPOSURES, 2-400 MHz

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Encl (1)

ABSTRACT

The potential usefulness of a protective-suit ensemble to reduce specific absorption rate (SAR) at submicrowave frequencies was studied using a full-sized, muscle-equivalent human model. In the past, such suits were used predominantly for microwave protection, but some highly conductive suits presented a very real fire hazard when arcing was considered. Suits made from partially conductive fabric were slightly less effective against microwaves but were much less flammable; moreover, their performance against other radiofrequencies has not been studied. Recently promulgated exposure standards have imposed theoretical maximum body-currents to limit extremity SAR to a 20 W/kg and have impacted certain occupational environments such as those surrounding radiofrequency (RF) transmitting towers and heat sealers. In the present research, reactive near-field irradiation conditions were used at 2.025 and 29.9 MHz, and quasi-near-field conditions were used at 80.0 and 400.0 MHz. Nonperturbing thermal probes were used to measure RF-induced temperature rises from which localized ankle SARs were calculated; a stand-on RF milliammeter recorded RF body-to-ground current over metallic groundplanes. Mean ankle SARs of greater than 23 W/kg were measured for some unprotected conditions, but with full ensemble protection (suit, hood, and overshoes), no mean ankle SAR exceeded 1.1 W/kg. The suit without the overshoes, however, did not reduce ankle SAR. At 29.9 and 80.0 MHz, the presence or absence of the hood caused relatively small SAR changes. We attribute the suit's ability in reducing ankle SAR to the partially conducting nature of the metal/textile material and to the ability of the overshoes to shunt RF current around the ankles. We recommend that further use of partially conducting fabrics be explored to provide practical means of minimizing occupational RF-induced extremity SAR.

Key Words: Radiofrequency, Protective Suit, RF Current, Near-field, SAR

INTRODUCTION

Radiofrequency (RF) body currents, both body-to-ground and hand-contact, are now subject to limitations imposed by recently promulgated occupational exposure guidelines.[1,2] In the past, most situations that produced such currents were ignored, probably because any RF-induced heating was usually confined to the wrists and/or ankles of workers in specific occupations such as tower-climbing riggers or RF heater operators and was, for the most part, hardly noticeable or noxious.

Whenever high contact currents occurred, there was a concomitant arcing and/or RF burn to unprotected fingers. Those conditions were usually well-defined and known to experienced workers who were protected, usually, through administratively imposed regulations. Whenever high body-to-ground currents occurred, ankle-warming sensations were noticed, usually without sequelae. Injury, therefore, was minimal, yet RF-induced body currents existed for years, even to thermalizing levels, in common workplace situations.

Those relatively low body currents might not have ever been "discovered" or limited had it not been for the rise of specific absorption rate (SAR) as the metric of RF/microwave bioeffects research. The 1982 ANSI guideline used SAR as the criterion of RF energy absorption.[3] Average, whole-body SAR was limited to 0.4 W/kg, but localized SARs could rise to 8.0 W/kg. The new guideline sparked instant interest in microwave and radio wave dosimetry. Gandhi and others began to study RF-induced SAR in the extremities, especially in the ankle where the anatomical cross-section is very small, and (for a given limb current) SAR is inversely proportional to the fourth power of the "effective" cross-sectional diameter.[4,5] Based on crude anatomical approximations and computer-generated calculations, extremely high SAR was predicted to occur in the ankle under ANSI-allowed exposure conditions.[6] Subsequent scrutiny, however, has produced evidence to show that, under more realistic assumptions of anatomical cross-sections and tissue electrical properties, ankle SAR was lower than first predicted.[7]

Recently, whole-body SAR and RF body-to-ground current were compared in a full-sized model for near-field irradiation in the 10-30 MHz range.[8] It was found that the occupational ankle-current limit (200 mA) was reached at near-field exposure intensities well below those necessary to produce the maximum allowable whole-body SAR (0.4 W/kg). Ankle current, therefore, was the critical factor in ground-coupled, near-field RF exposure. Other recent studies have clearly indicated that significant SAR and foot currents exist in RF heater operators near the machine during irradiation.[9,10] Reducing or completely eliminating such currents would be a desired feature in any exposure-reduction scheme.

Microwave-protective suits have been evaluated previously for worker protection for frequencies above 915 MHz.[11,12] At such frequencies, highly directional sources and front-surface heating of the body are common. Some tested suits were very effective in electromagnetic (EM) attenuation but were sufficiently flammable to argue against regular use. Less conductive EM-protective suits reduced the fire hazard potential, but still provided relatively good protection, especially above 2 GHz. Suit protection characteristics at frequencies less than 100 MHz are not known. Such frequencies are occupationally important to operators of industrial RF heaters and to workers at or near commercial broadcasting facilities. To fill this gap in knowledge, we conducted experiments to investigate the ability of a commercially available EM-protective suit to reduce ankle SAR in a full-size human model exposed to a range of submicrowave frequencies.

METHODS

Apparatus. The protective suit was made of Naptex-30 with a weight of 200 g/ m^2 (full flame retardant ensemble weighed 1.58 kg). This material looks and feels much like broadcloth, but the yarn consists of polyester and stainless steel fibers enveloped in cotton. It is designed to be reflective to EM radiation over a wide range of radiofrequencies. A full protective ensemble consisted of coveralls, flanged hood with a metal viewing screen, and high-top overshoes with Naptex sandwiched between two thin foam rubber soles. Another pair of partial overshoes had no Naptex under the foot. Both overshoe types had Velcro closures that overlapped the lower coveralls for 15-20 cm. Naptex is manufactured by NSP-Sicherheits-Produkte GmbH of Nordendorf, Germany, and is distributed in the United States by Maxwell Safety Products of Hauppauge, New York.

A full-size, muscle-equivalent human model was used in testing the protective suit and has been previously described.[13] The legs of the model were constricted to a 6-cm diameter using sections of plastic pipe to form simulated ankles. The muscle-equivalent material used to fill the model was composed of water, gelling agent, finely ground aluminum powder, and sodium chloride as previously described.[14]

Tests at 2.025 MHz and 29.9 MHz were conducted as shown in Figure 1 at a high-frequency (HF) groundplane-irradiation facility at the Naval Air Station, Pensacola, Florida. The irradiation system consisted of a 10.8-m monopole (whip antenna) centered over a 9.4 x 10.8 m wire-mesh groundplane. The RF energy was generated by a synthesized RF source (Model 6062A, John Fluke Manufacturing Co., Inc., Everett, WA) and amplified in a 1.0-kW broadband amplifier (Model A1000, ENI, Inc., Rochester, NY). At 2.025 MHz, a full kilowatt was radiated; at 29.9 MHz, 950 W was used.

The 80- and 400-MHz tests were conducted at the Naval Surface Warfare Center, Dahlgren, Virginia (see Figure 2). The 80-MHz irradiation system consisted of a yagi antenna (Model Y53-70, Taco Corp., Sherburne, NY) positioned over a 24 x 48 m groundplane consisting of welded steel plates. The signal was produced by a synthesized RF source (Model 8640B, Hewlett-Packard Co., Santa Clara, CA) and a 1.0-kW amplifier (Model IFI-406, Instruments For Technology, Ronkonkoma, NY). The system for 400 MHz utilized the same groundplane and signal source. A smaller yagi antenna (Model Y53B-355, Taco Corp., Sherburne, NY), appropriate for 400 MHz, was used with a 1.0-kW amplifier (Model 10110, MCL, Bolingbrook, IL). Total power density was measured using an isotropic (E-field) probe and power density monitor (Models 8762/8716, Narda/Loral, Inc., Hauppauge, NY). In the absence of the model, power density data were recorded at three heights above the groundplane (legs, mid-torso, and head) and then averaged. At 2.025 MHz, power density was recorded at one-fourth of full power. Body-to-ground current through both feet was measured using a prototype stand-on RF current meter (Model GC-2, University of Utah, Salt Lake City, UT). Specific absorption rates were calculated from measurements of temperature rise made with nonperturbing probes.[15]

Procedures. At 2.025 MHz, the model was placed 1.22 m from the base of the antenna; at 29.9, 80.0 and 400.0 MHz, the spacing was 1.83 m due to the much higher body-to-ground currents and field strengths. In a typical SAR measurement, the thermal probes were inserted to a mid-depth of 3 cm into the ankle and allowed to stabilize for a few minutes. A 5-min pre-exposure baseline was then commenced by recording temperatures at 1-min intervals without irradiation. Next, the model was irradiated for 5 min with the same sampling intervals. Localized SAR, in W/kg, was calculated as the product of the material specific heat (in units of joules per kg per degrees C) and the net RF-induced heating slope (in degrees C per sec); that is, the slope during irradiation minus any baseline slope.[15] For an individual irradiation, left and right ankle SARs were considered to be individual measurements for analysis.

At 2.025, 29.9, and 80.0 MHz, several configurations of protective clothing were tested including a "NO SUIT" control. At 400 MHz, only the control and the full protective ensemble were tested. Two to four SAR measurements were made for each condition.

RESULTS

Table I is a summary of our results. It is interesting to note that, for the three lowest frequencies, addition of only the suit and hood increased both body-to-ground current and ankle SAR. The unprotected ankle SAR per unit of power density was highest at 29.9 MHz (as expected) and remained relatively high at the (free-space) resonant frequency of 80.0 MHz. At all frequencies, addition of either partial or full overshoes greatly reduced ankle SAR. The "No Hood" results at 29.9 and 80 MHz show the hood to be superfluous (with respect to ankle SAR) for relatively longwavelength irradiation. At 29.9 and 80 MHz, the (Full Ensemble) ankle SAR "safety factors" were 18.2 and 28.6 respectively, which figures technically imply that the power densities could rise by those factors before mean ankle SAR would reach 20 W/kg.

The near-field nature of the irradiation at the lowest two frequencies must be stressed, especially in conjunction with the recorded power densities. The proximity of the human model to the radiating source resulted in a highly nonuniform irradiation configuration and one in which the model was reactively coupled to the antenna. The recorded power densities must not be confused with far-field plane-wave densities that exist at farther distances with only a vertical E-field component.

DISCUSSION

These results show that RF-induced SAR can be reduced with certain configurations of protective apparel that, historically, have only been used for microwave protection. When the full overshoes were used, the beneficial effect was seen over a wide spectrum. The full protective ensemble changed out-of-compliance and borderline exposure situations into ones that were not only in compliance but also with a wide margin of safety.

If the Naptex fabric were highly conductive in a metallic sense, we could explain the observed ankle-SAR reduction as a direct result of the RF "skin effect"; that is, the phenomenon wherein the majority of RF current in a conductor flows near the surface. A conducting "wire," therefore, could be a hollow metal tube with little difference. Unfortunately, Naptex is not a true conductor, so we surmise that the ankle-SAR reduction resulted from the combination of two factors; namely, the finite RF conductivity of the fabric and the increased area of fabric-to-ground capacitive coupling produced by the overshoes. The finite conductivity resulted in a useful skin effect, and the increased coupling provided a path of lower resistance to ground outside the ankles. These factors did not reduce the current-to-ground at 29.9 and 80.0 MHz as indicated by the stand-on RF milliammeter; that current appeared to increase, perhaps, because of an increased "fringing" or "flanking" current around the ankles.

CONCLUSIONS AND RECOMMENDATIONS

"Microwave-protective" suits with overshoes may have a useful function at radiofrequencies below the microwave spectrum; specifically, in the reduction of RF ankle current, which has been shown to be the limiting factor in certain near-field exposure situations. From these data, we assume that whole-body average SAR was also reduced. Previously published block-model computer simulations of grounded humans irradiated near the resonant frequency showed leg SAR to be the highest of any body part and was approximately twice the whole-body average.[16] If ankle and leg SAR were greatly reduced, average SAR would also be much lower, probably in direct proportion to reduction in ankle SAR.

We recommend that quasi-conductive fabrics such as Naptex be given more attention in areas of body current/SAR reduction in occupational situations that involve RF exposure. This material, while not putatively conductive, is not highly flammable like previously used conductive fabrics. Naptex has been shown to provide a useful effect of shunting RF current around the ankle. Although our measurements extended only to 400 MHz, there is no reason to expect the microwave-protective properties of Naptex to be different from other similar materials that have performed well up to 11 GHz.

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FIGURE CAPTIONS

Figure 1. The suit-protected human model is shown atop the RF milliammeter at the 29.9 MHz irradiation location. The wire-mesh groundplane surrounding the antenna is not visible.

Figure 2. At 80 MHz, the yagi antenna was supported (vertically polarized) by a foamed polystyrene billet over welded steel decking.

ACKNOWLEDGMENTS

Funding for this project was provided by Maxwell Safety Products in accordance with a Cooperative Research and Development Agreement between the Naval Medical Research and Development Command/Naval Aerospace Medical Research Laboratory, and Maxwell Safety Products, Ltd.

The views expressed in this article are those of the authors and do not reflect the official policy or position of the Department of the Navy, Department of Defense, nor the U.S. Government.

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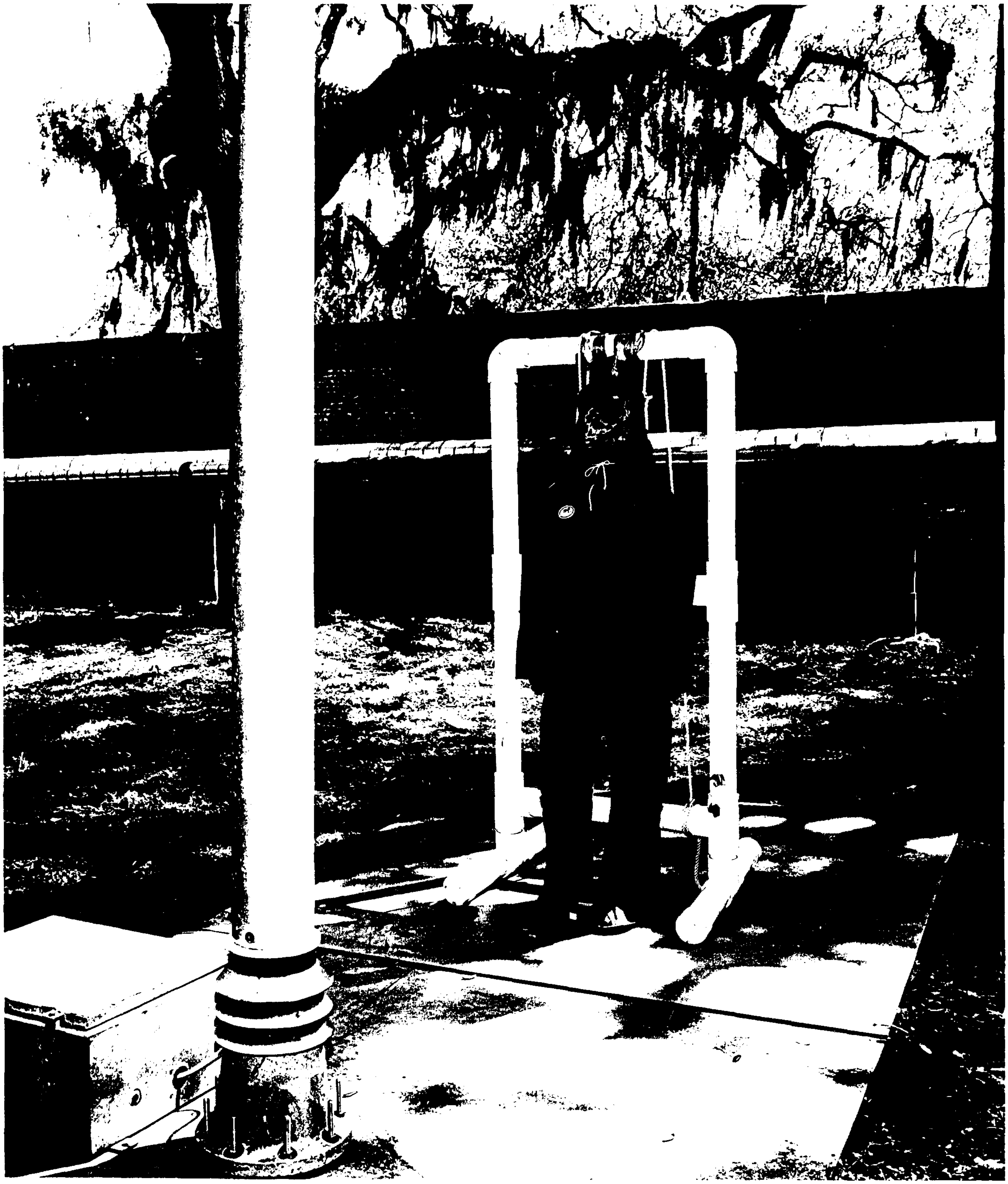

Figure 1. The suit-protected human model is shown atop the RF milliammeter at the 29.9 MHz irradiation location. The wire-mesh groundplane surrounding the antenna is not visible.

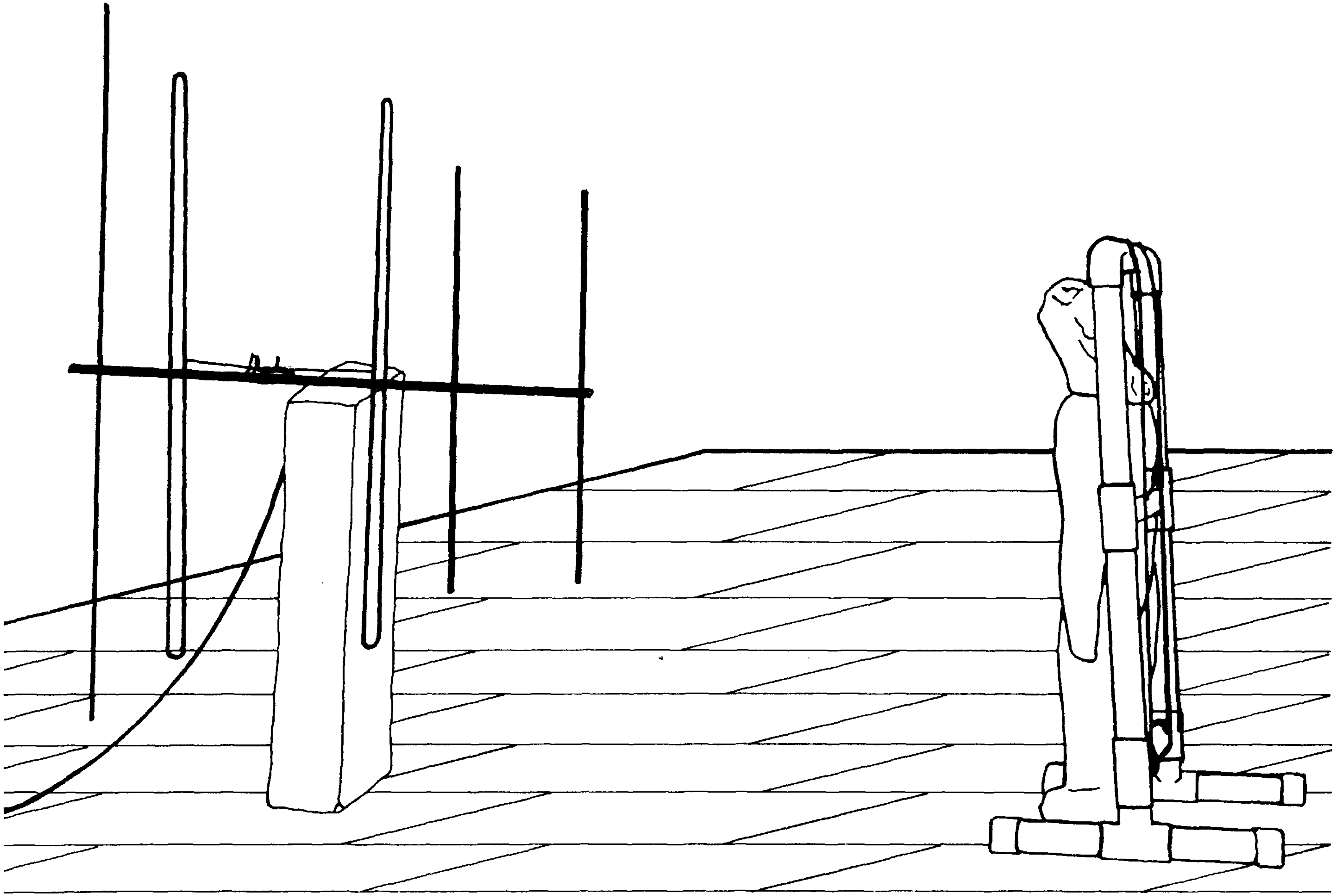

Figure 2. At 80 MHz, the yagi antenna was supported (vertically polarized) by a foamed polystyrene billet over steel decking.

Table I. Summary of the near-field irradiation results.

Suit Configuration	Body-to-ground Current, mA	Mean Ankle SAR ± SD, W/kg
2.025 MHz & 463 mW/cm^2		
No Suit	213	2.4 ± 0.6 (n=6)
Suit & Hood	256	2.7 ± 0.7 (n=6)
Suit & Hood & Full Overshoes	115	0.0 ± 0.2 (n=4)
29.9 MHz & 2 mW/cm^2		
No Suit	598	15.5 ± 2.6 (n=8)
Suit & Hood	840	15.7 ± 4.4 (n=8)
Suit & Hood & Partial Overshoes	609	2.6 ± 2.6 (n=8)
Suit & Hood & Full Overshoes	674	1.1 ± 0.7 (n=8)
Suit (No Hood) & Full Overshoes	645	0.7 ± 0.2 (n=4)
80.0 MHz & 9 mW/cm^2		
No Suit	640	19.1 ± 0.4 (n=6)
Suit & Hood	700	23.7 ± 1.4 (n=6)
Suit & Hood & Partial Overshoes	760	1.7 ± 0.6 (n=6)
Suit & Hood & Full Overshoes	740	0.7 ± 0.2 (n=5)
Suit (No Hood) & Full Overshoes	640	0.3 ± 0.5 (n=6)
400.0 MHz & 10 mW/cm^2		
No Suit	122	2.2 ± 0.3 (n=4)
Suit & Hood & Full Overshoes	110	0.0 ± 0.1 (n=4)

MICROWAVE TESTING USING *NAMRL's* FULL-SIZED HUMAN MODEL, 1000-15,000 MHz

SYNOPSIS OF NAPTEX-PROTECTED "GREEN-MAN" SAR RESULTS FROM WTD-81, GREDING, GERMANY DURING SEPTEMBER, 1993

Recently, personnel from the Naval Aerospace Medical Research Laboratory (NAMRL) visited WTD-81 in Greding, Germany. They constructed a full-size, muscle-equivalent human model ("green man") that had been previously used in many microwave and radiofrequency dosimetric evaluations in the U. S. Navy. The purpose of the "green man" at WTD-81 was to test the effectiveness of Naptex fabric at several microwave frequencies.

A nonperturbing (Vitek-type) thermal probe was used to record tissue temperature at a depth of approximately 3 mm behind the front surface of the human model that was irradiated with high-intensity continuous-wave (CW) microwave energy at 1.0, 6.0, 8.5, and 15 GHz. Specific absorption rate (SAR) was calculated from the probe readings for both unprotected and Naptex-protected conditions. In addition, a second probe recorded the surface temperature of the irradiated Naptex fabric at 6.0, 8.5, and 15 GHz. The accompanying bar graph illustrates the following results.

For a normalized power density of 100 mW/cm^2 at 1.0 GHz, unprotected SAR was 9.5 W/kg; behind the face screen, SAR was only 0.1 W/kg, a factor of 95 (-19.9 dB) lower.

At 6.0 GHz and 100 mW/cm^2, unprotected SAR was suspiciously low at 4.2 W/kg. Only one measurement of unprotected SAR was made, and the temperature probe might have slipped farther away than 3 mm from the front surface. Naptex-protected SAR was only 0.6 W/kg, a factor of 7 (-8.5 dB) lower. We cannot explain the relatively low 6.0-GHz reduction factor results.

At 8.5 GHz and 100 mW/cm^2, average unprotected SAR was 17.5 W/kg; protected SAR was 1.4 W/kg, a factor of 12.5 (-11 dB) lower.

At 15 GHz and a normalized power density of 100 mW/cm^2, average unprotected SAR was 18.4 W/kg; whereas, SAR behind the face screen was only 0.22 W/kg (-19.3 dB), and Naptex-protected body SAR was only 0.66 W/kg (-14.5 dB).

The average SAR reduction factor was 45.2, and the average decibel reduction was -14.6 dB. We conclude that Naptex provides SAR protection over a wide range of microwave and radio wave frequencies. From these data and a knowledge of the physical nature of Naptex fabric, we believe that the WTD-81 test results could be generalized over the spectrum from about 0.4 GHz to approximately 30 GHz. Any questions regarding these results should be directed to Dr. Richard G. Olsen, Naval Aerospace Medical Research Laboratory, 51 Hovey Rd, Pensacola, FL 32508-1046 USA; telephone 904-452-2038, telefax 904-452-4479.

The information provided represents continuing testing carried out by a U.S. Air Force program to determine the efficacy of RF Protective Clothing. This information above specifically addresses the microwave radiation protective properties of Naptex, without the use of overshoes which are required for operation below 300 MHz. For proven performance information below 300 MHz, contact Maxwell Safety Products at (516)-366-2411 or fax (516)-361-6135.

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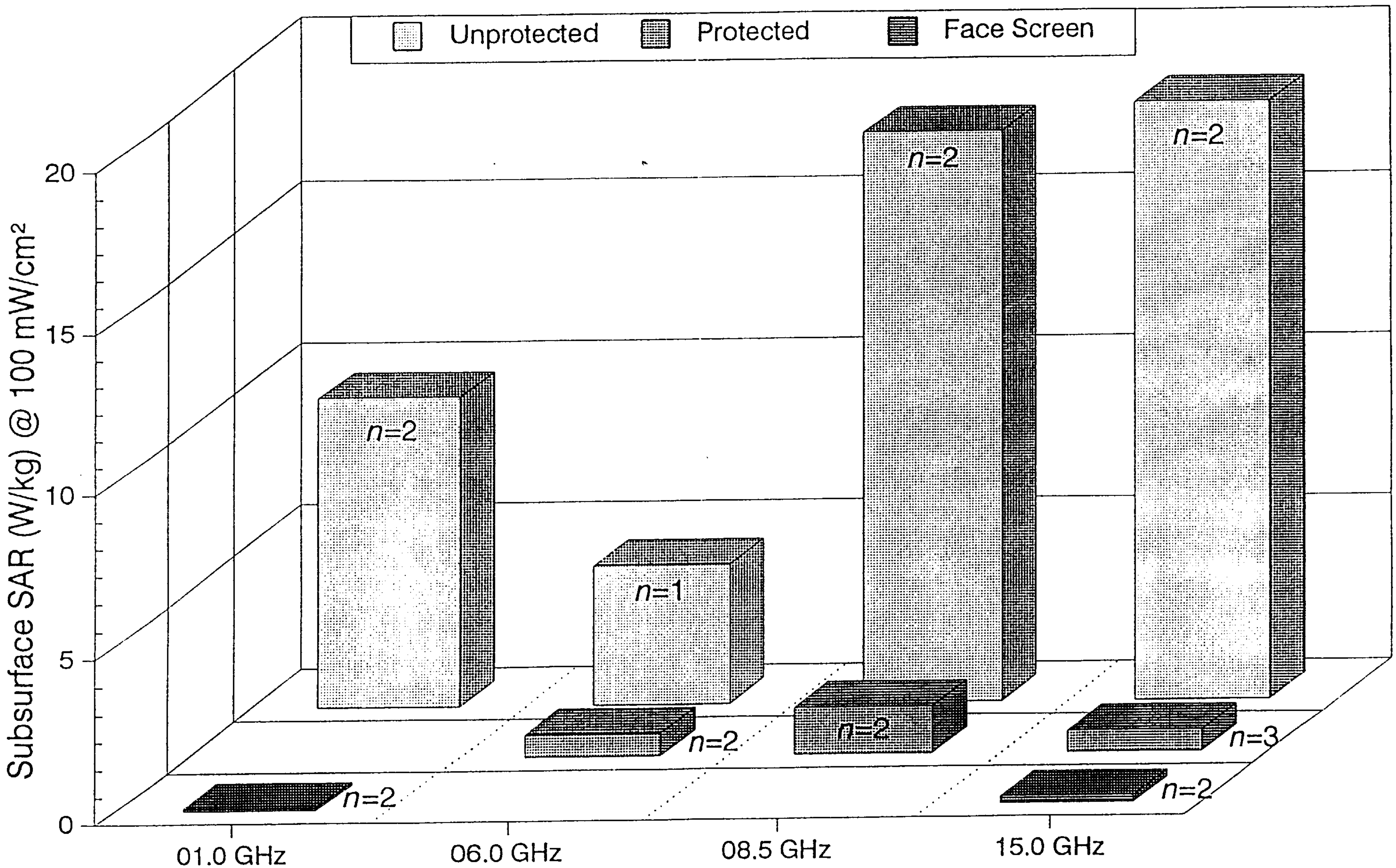
GRAPHICAL COMPOSITE OF MICROWAVE TEST RESULTS



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Naptex Surface Temperature

@6.0, 8.5, 15.0 GHz